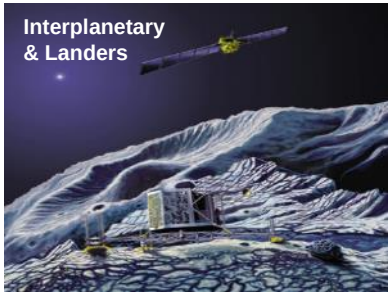
# Thermal Runaway Testing of 18650 Lithium Ion Cells




POWERED *by*

ABSL QUALLION

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# Overview

- **Reason for thermal runaway testing of 18650 cells**
- **Single cell thermal runaway testing**
  - Develop method of heating cells into thermal runaway
  - Gain understanding of cell behavior during thermal runaway
  - Gain understanding of the temperature range of initiation of thermal runaway
  - Gain understanding of peak external cell temperature during thermal runaway
- **Battery level thermal runaway testing**
  - Determine if ABSL standard designs can structurally withstand thermal runaway
  - Determine if ABSL standard design principles allow for propagation of thermal runaway

## What drove the need for thermal runaway testing?

- **Increased general awareness of the risk of thermal runaway**
- **Manned mission requirements**
  - Until recently, ABSL batteries were used mainly on non-manned missions
- **Cell Energy densities are increasing**
  - Increased stored energy increases consequence of thermal runaway

# Method of Thermal Runaway Initiation

- **An external heater was used to heat cells into thermal runaway**
- **Nichrome wire was manually formed into a small heater element**
- **The heater element was then attached to the cell using kapton tape**
  - Addition of a wire wrap around the kapton covered heater to keep heater from coming off the cell as the kapton is heated past the melting point of the adhesive
- **Constant voltage is applied to the heater until the cell went into thermal runaway**
  - During testing, heaters typically powered at 30 W to 50 W

# Single Cell TR Testing to Characterize Cell Behavior

- **Testing was first performed on Sony 18650HCM cells**
- **The HCM is a 1.5 Ah cell**
- **As the HCM approaches thermal runaway, it begins to vent a small amount of smoke**
  - The cells would typically vent smoke for 10-15 seconds prior to going into full thermal runaway
- **At the time of thermal runaway, a jet of flame, sparks, and smoke are emitted through the center of the cathode assembly**
  - During thermal runaway, the jet would typically last 2-3 seconds
- **Cell can temperature was hot enough to ignite the kapton tape wrap and cause additional fire around the anode, or can, of the cell**

# HCM Single Cell TR Test


# HCM Single Cell TR Test

- **The cells were visually inspected following TR**
- **Cathode assembly remained intact**
  - The TR jet pierced through the burst disk and cathode top cap
- **No signs of side wall rupture in the anode**
- **Heat discoloration of the cell can**

# Single Cell TR Testing to Characterize Cell Behavior

- **Testing was then performed on the Molicel IHR-18650C (Moli C) cells**
- **The Moli C is a 2.2 Ah cell**
- **As the Moli C approaches thermal runaway, it is much less consistent than the HCM cell**
  - Some cells would vent a significant amount of smoke, others would vent no smoke
- **At the time of thermal runaway, the crimp holding the cathode assembly would fail**
  - The cathode assembly was blown out of the cell
  - The internal jelly was blown out of the cell can
  - Thermal runaway is much more energetic than the HCM
- **Thermal runaway of the Moli C is much shorter duration than HCM**
- **During cell level testing, flames were not observed coming out of cell**
- **Cell can temperature was hot enough to ignite the kapton tape wrap and cause additional fire around the anode, or can, of the cell**

# Moli C Single Cell TR Test



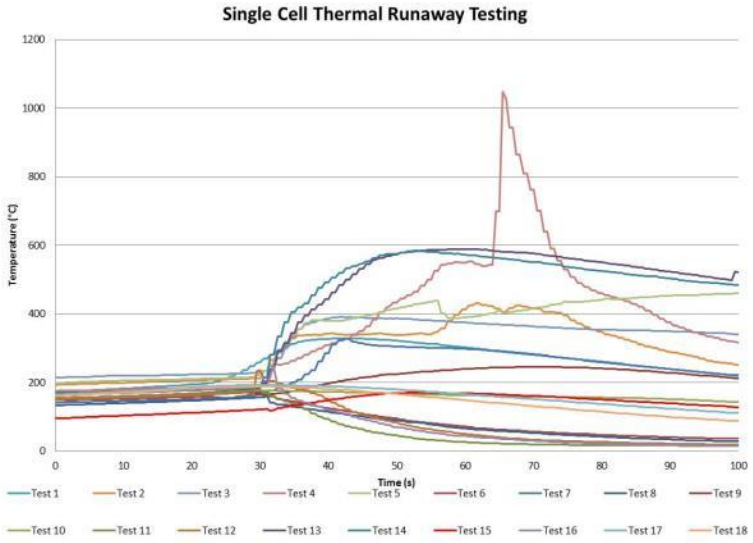


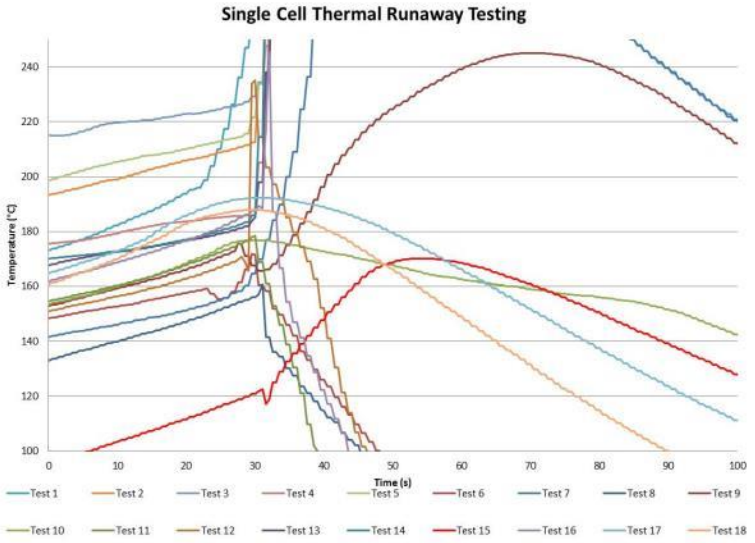
# Moli C Single Cell TR Test

- The cells were visually inspected following TR
- Cathode assembly ejected from the cell
- The jelly roll was ejected from the cell
- No signs of side wall rupture in the anode, but the can show significant bulging from the internal pressure
- Heat discoloration of the cell can

# Single Cell TR Temperatures

- **TR initiation temperature varied between tests**
  - Between 120°C and 230°C
- **Peak temperature during TR varied between tests**
  - Measured a peak of 1100°C
- **Some of the variation attributed to thermocouple placement and adhesion to the cell**
  - Peak temperatures were impacted by being engulfed in burning kapton flames



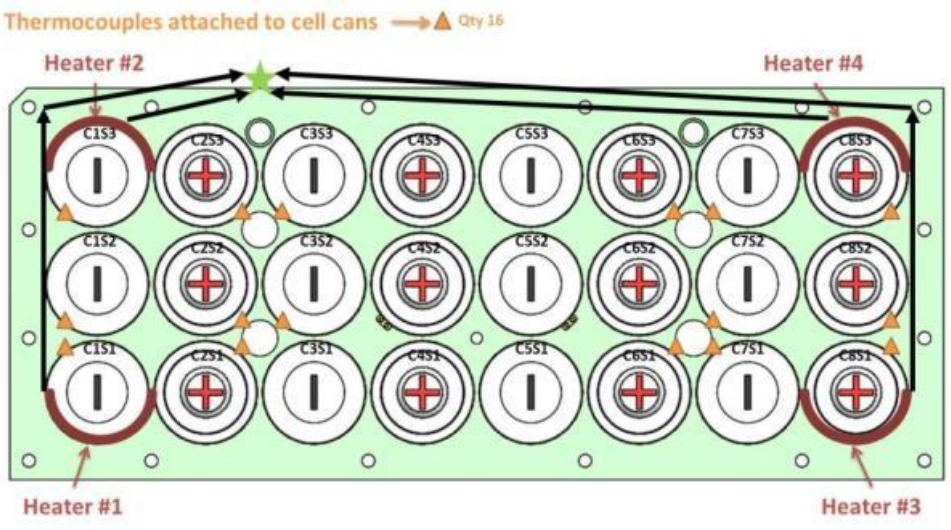



# Battery Level TR Testing

- TR at the single cell level poses significant risk on its own
- At battery level though, the concern becomes that the single cell TR will heat neighboring cells to the point of TR, and then propagate to some or all remaining cells in the battery
- In addition to the risk of propagation of TR at the battery level, there is the question if the battery housing can maintain structural integrity
- To address these questions, following single cell testing, multiple cells were built into flight like configurations and tested at battery level

# HCM Battery Level TR Test

- **A 3p8s battery was built**
  - The battery was fully functioning electrically
  - It was built using all ABSL standard manufacturing processes for flight batteries, and was compliant to all applicable NASA and IPC standards
- **Battery had 2 flight temperature sensors and 16 thermocouples attached to the cells to measure cell can temperatures**
- **A heater was placed on the 4 corner cells of the cell block**
  - The corner cells were chosen because the represented a worst case scenario

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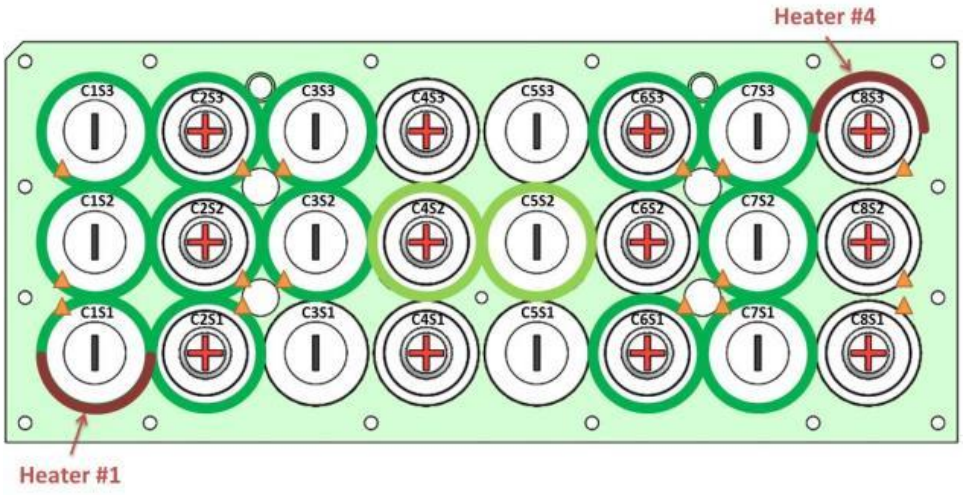
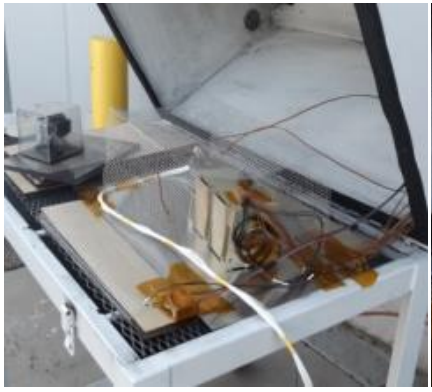
# HCM Battery Level TR Test 1

- The first test on the HCM battery was run using the Heater #1 cell (lower left corner of image below)
- The thermocouples on the cells circled in dark green were monitored
- The flight temperature sensors on the cells circled in light green were also monitored

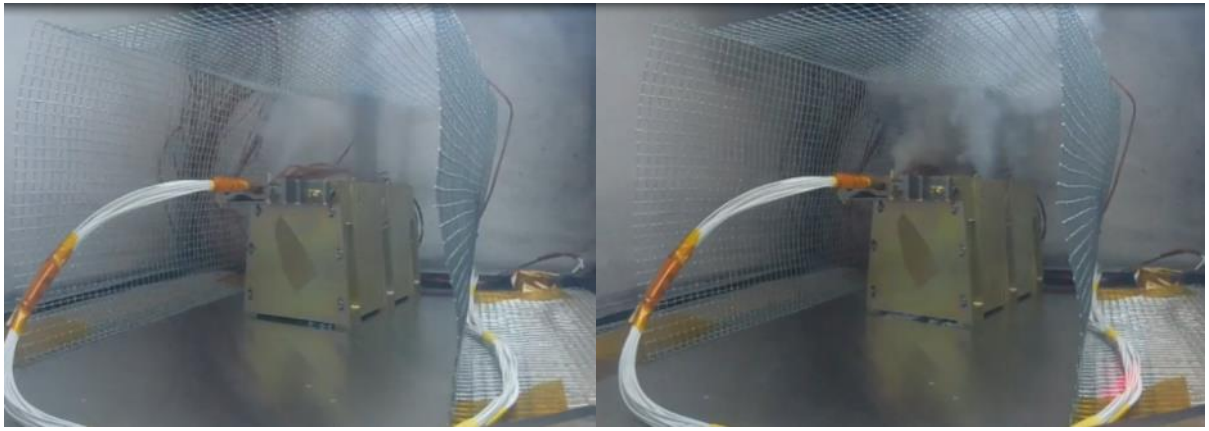


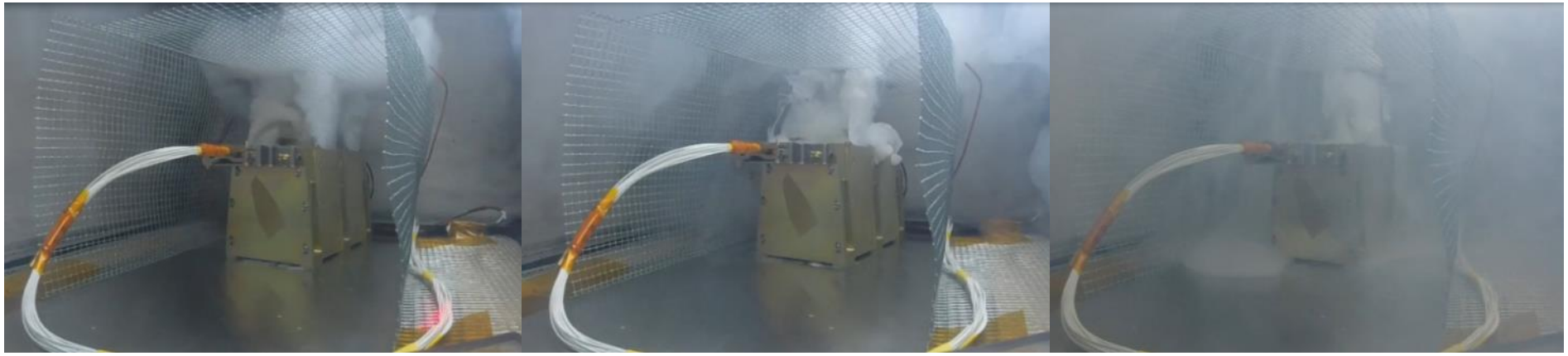



# HCM Battery Level TR Test 1

- The trigger cell went into TR as expected
- The entire TR even lasted roughly 17 seconds
- No flames or sparks were observed during the TR
- There was no propagation of TR
- The battery maintained structural integrity and exhibited no signs of structural damage on the outside of the battery

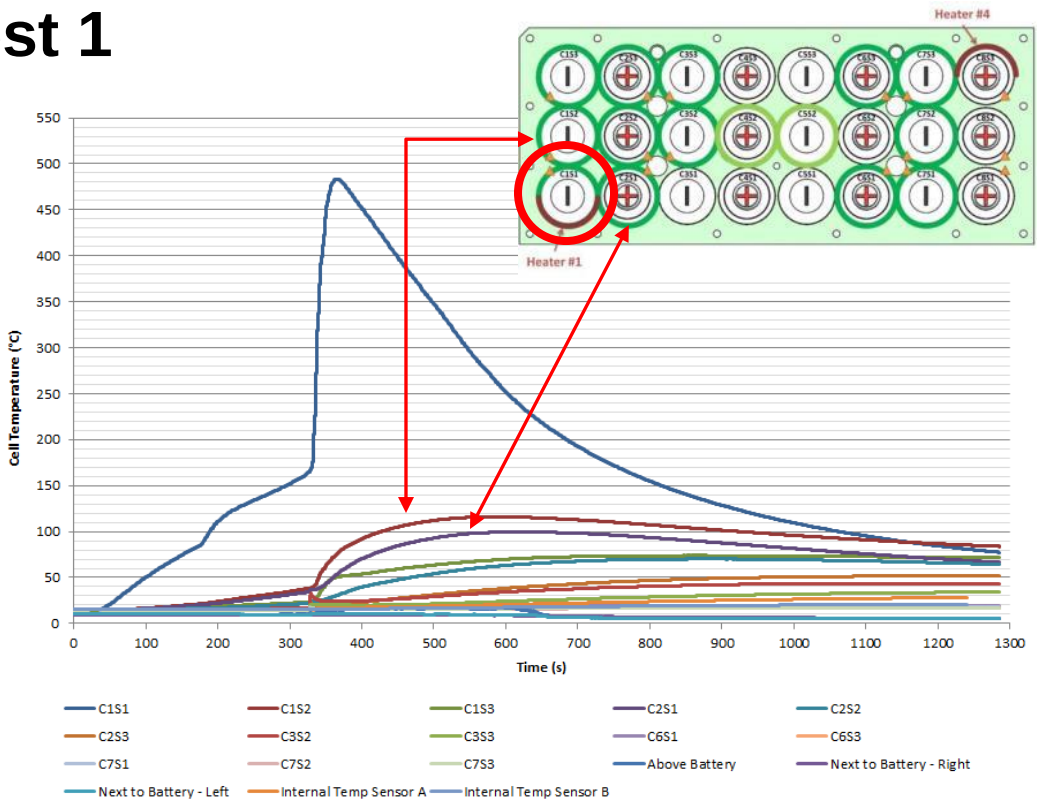
# HCM Battery Level TR Test 1

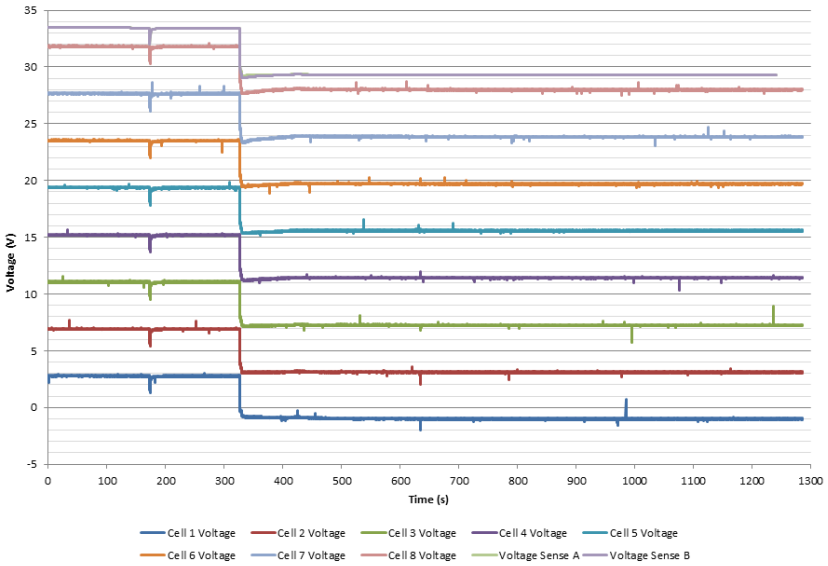




# HCM Battery Level TR Test 1

- **TR on the trigger cell started at approximately 165°C**
- **The maximum temperature observed in the neighboring cells was approximately 120°C**
  - Only two of the neighboring cells went over 100°C, all other cells remained under 70°C to 80°C

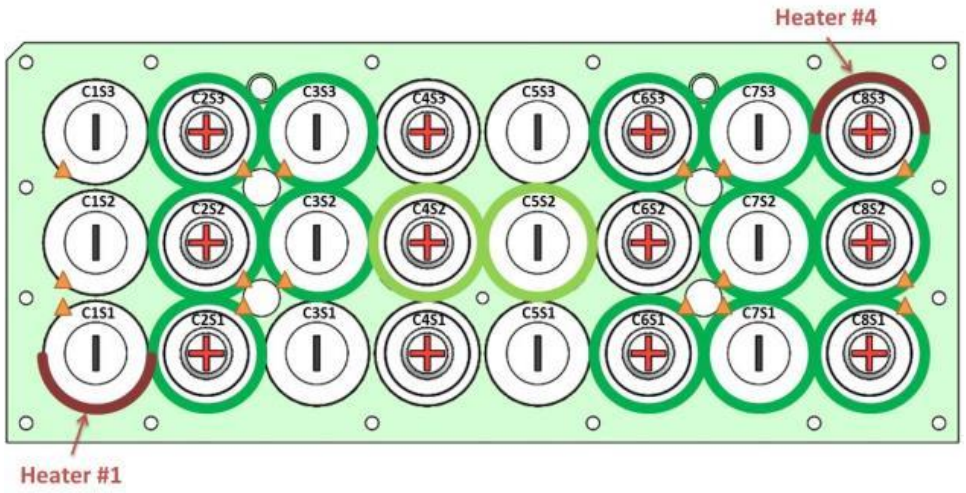



- **Virtual cell voltages were monitored during the test**
- **Cell 1, the trigger cell, shorted during the TR, but all other cells in the string show constant voltage and show no signs of additional shorting**

# HCM Battery Level TR Test 2

- The second test on the HCM battery was run using the Heater #4 cell (upper right corner of image below)
- The thermocouples on the cells circled in dark green were monitored
- The flight temperature sensors on the cells circled in light green were also monitored

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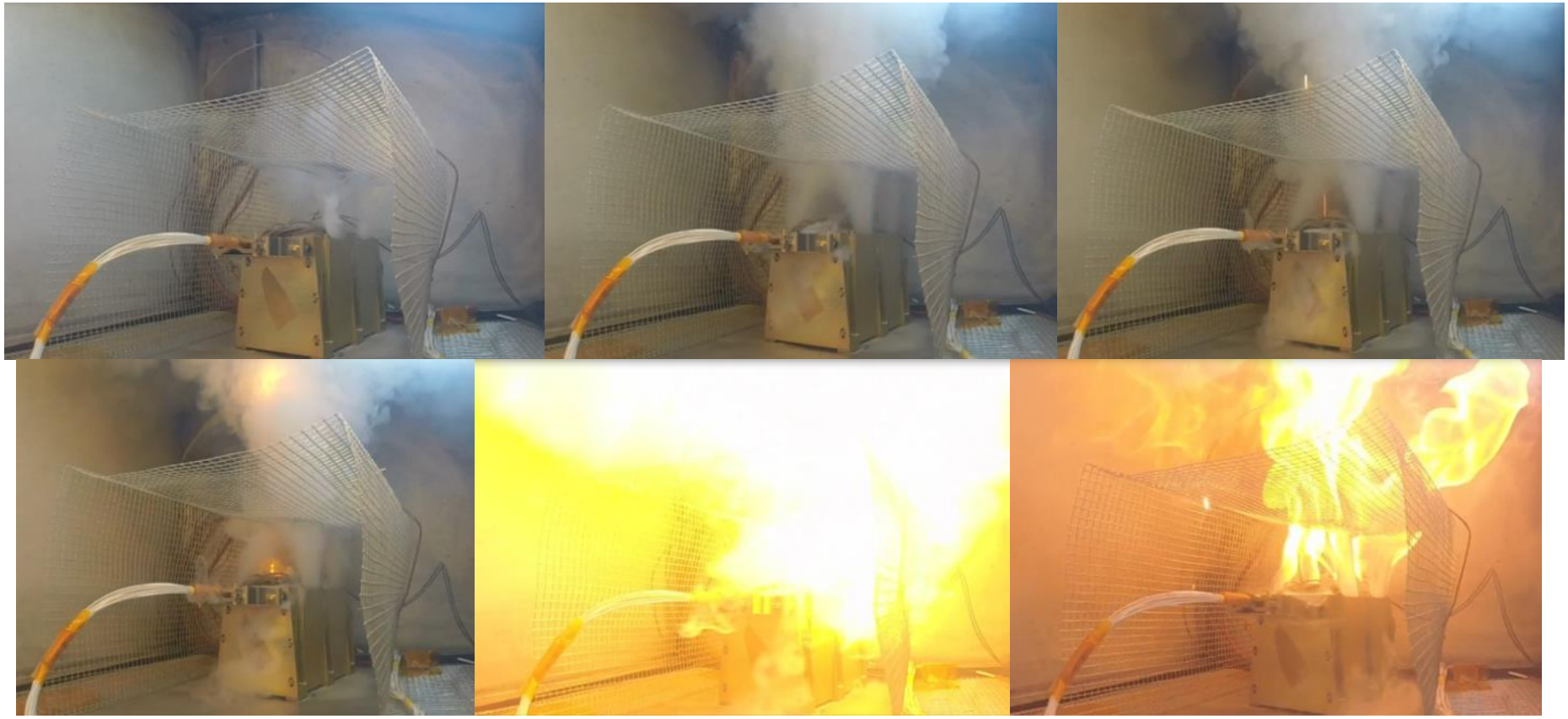
# HCM Battery Level TR Test 2

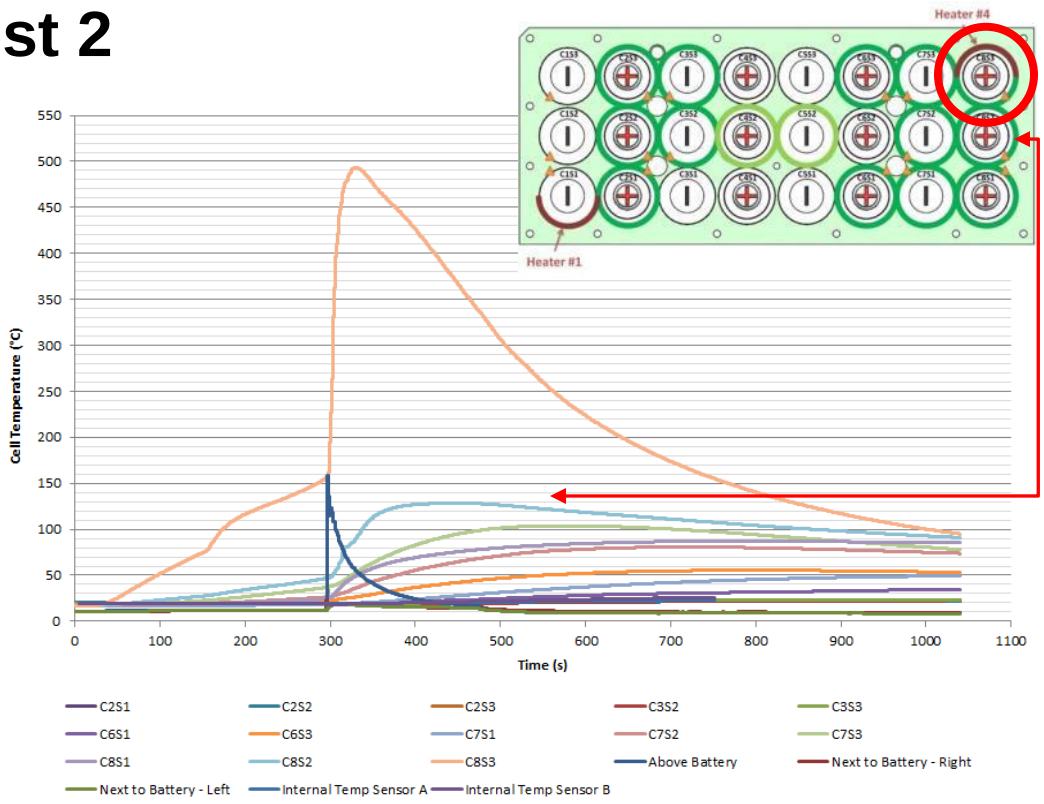
- The trigger cell went into TR as expected
- The entire TR even lasted roughly 20 seconds
- After TR initiation, a single spark appears to be ejected that then ignites flammable gases in the test chamber
- There was no propagation of TR
- The battery maintained structural integrity and exhibited no signs of structural damage on the outside of the battery

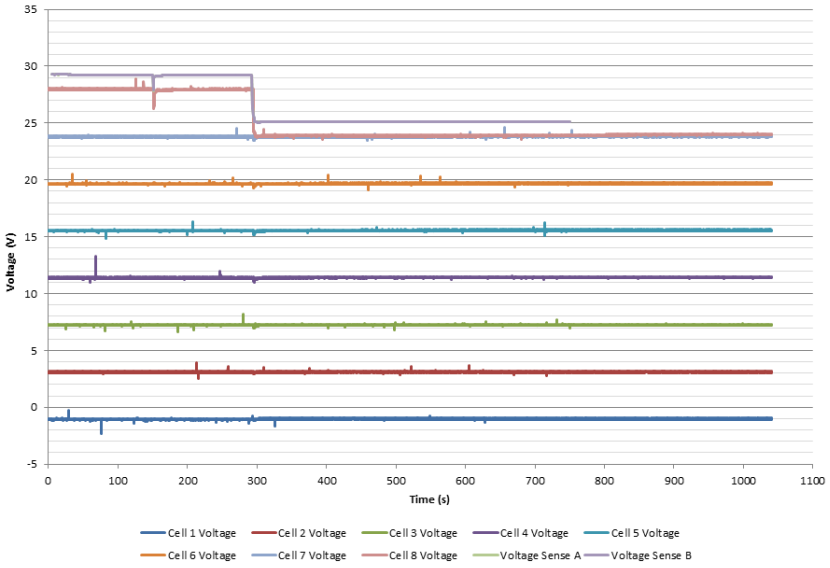
# HCM Battery Level TR Test 2



# HCM Battery Level TR Test 2

- **TR on the trigger cell started at approximately 160°C**
- **The maximum temperature observed in the neighboring cells was approximately 130°C**
  - Only two of the neighboring cells went over 100°C



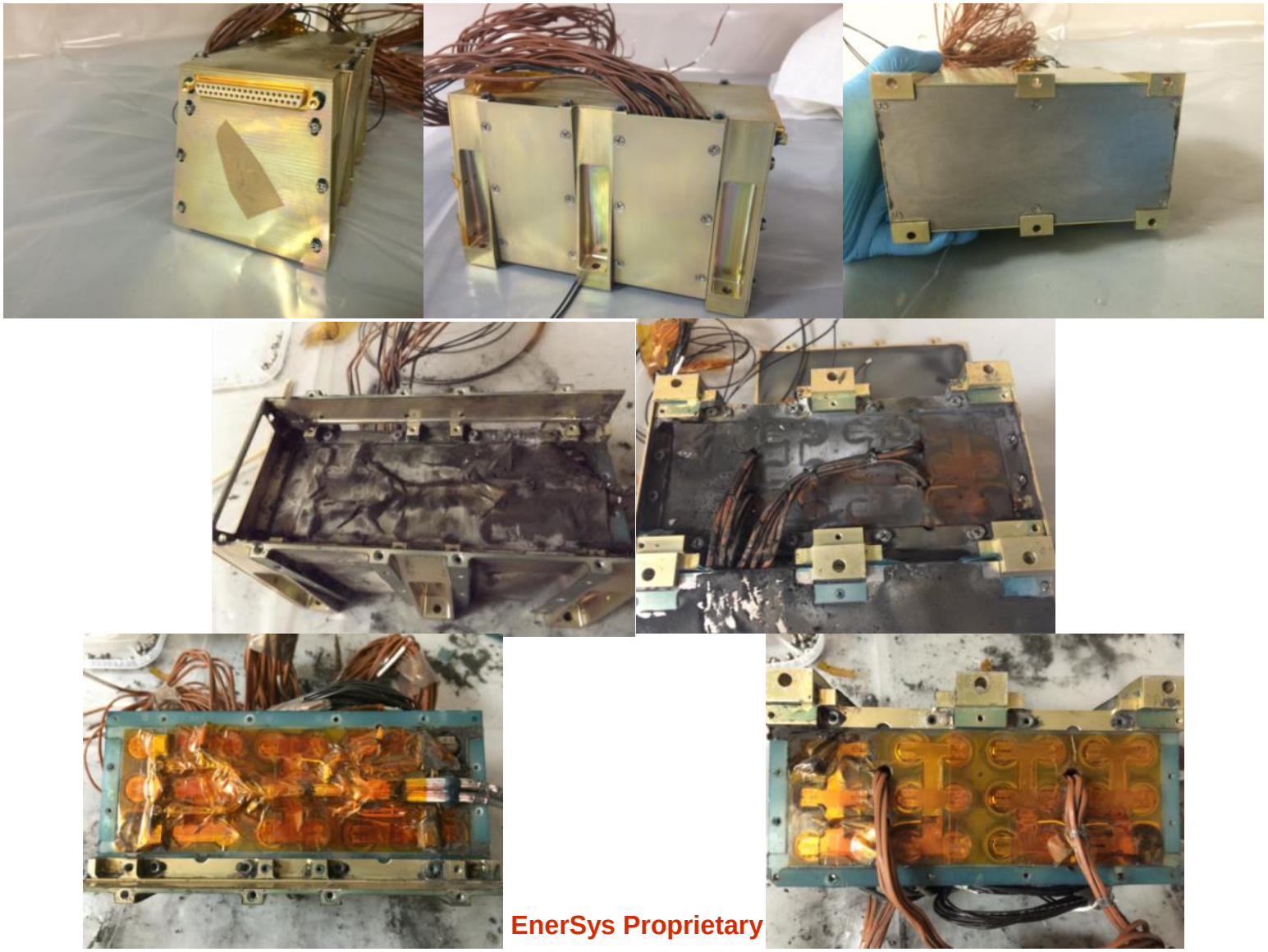




- **Virtual cell voltages were monitored during the test**
- **Cell 8, the trigger cell, shorted during the TR, but all other cells in the string show constant voltage and show no signs of additional shorting**

## HCM Battery Post TR Disassembly

- **Following TR testing, the battery was disassembled**
- **No signs of propagation were found when the battery was disassembled**
- **No signs of structural damage were found**

# HCM Battery Post TR Disassembly



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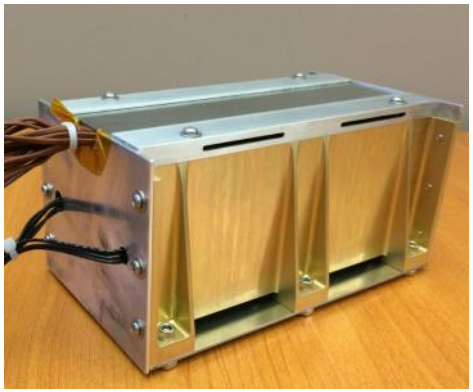
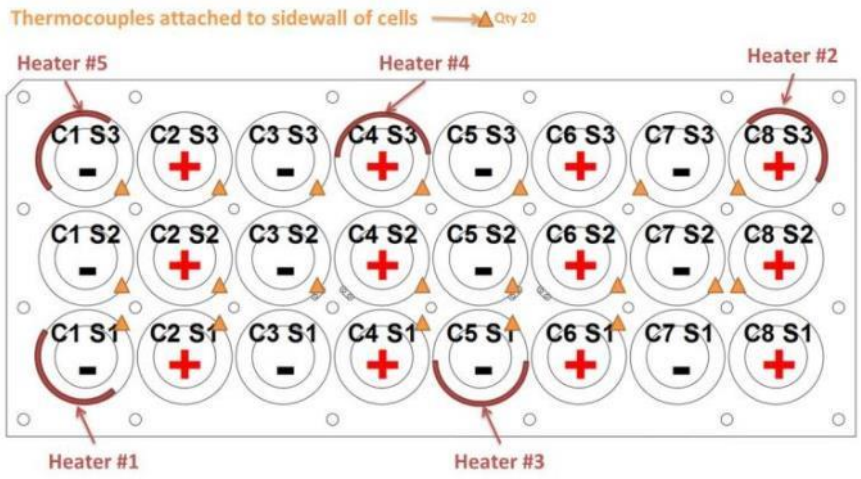
# Moli C Battery Level TR Testing

- **Moli C battery level testing followed the HCM battery level testing**
- **Moli C cells were set up in two battery configurations**
  - 24 cells in each
  - One battery built with chassis similar to the HCM battery
    - Cells were not connected electrically
  - Second configuration did not have chassis
    - Cells were connected electrically in 4 individual 6p1s modules

# Moli C Battery Level TR Test 1

- **24 cells built into the same cell block configuration as the HCM battery**
  - The cells were not connected electrically
- **Battery had 20 thermocouples attached to the cells to measure cell can temperatures**
- **5 heaters were placed on the cells as shown**
  - Tests were run using heater #1, #3, and #4 (showing results for heater #1)





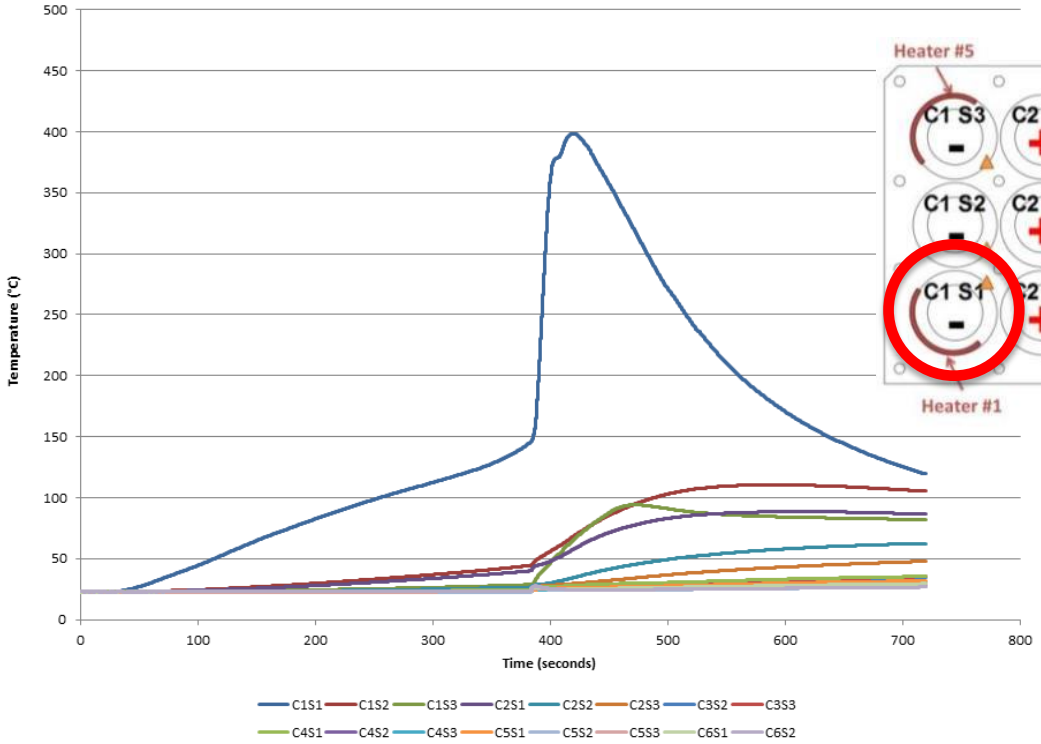

# Moli C Battery Level TR Test 1

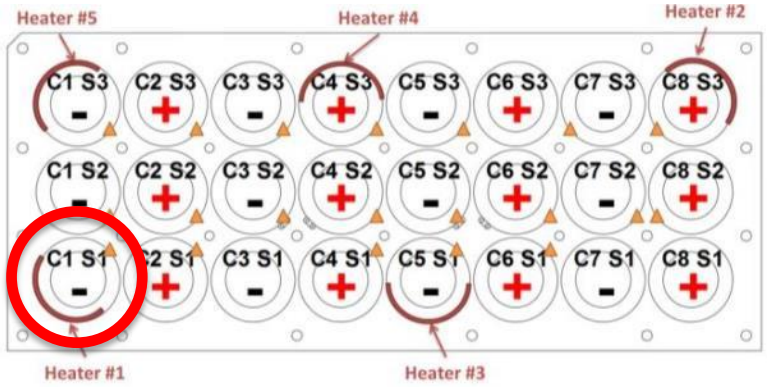
- The trigger cell went into TR as expected
- No propagation of TR occurred
- Battery maintained structural integrity
- No flames were visible during the TR
- Cathode was blown off the cell during
- Fragments of the jelly roll were ejected
- Jelly roll material was deposited on neighboring cells resulting in one cell shorting (C1S2)
- The anode showed severe swelling due to the TR

# Moli C Battery Level TR Test 1

# Moli C Battery Level TR Test 1

- **TR on the trigger cell started at approximately 150°C**
- **The maximum temperature observed in the neighboring cells was approximately 115°C**
  - Only one of the neighboring cells went over 100°C

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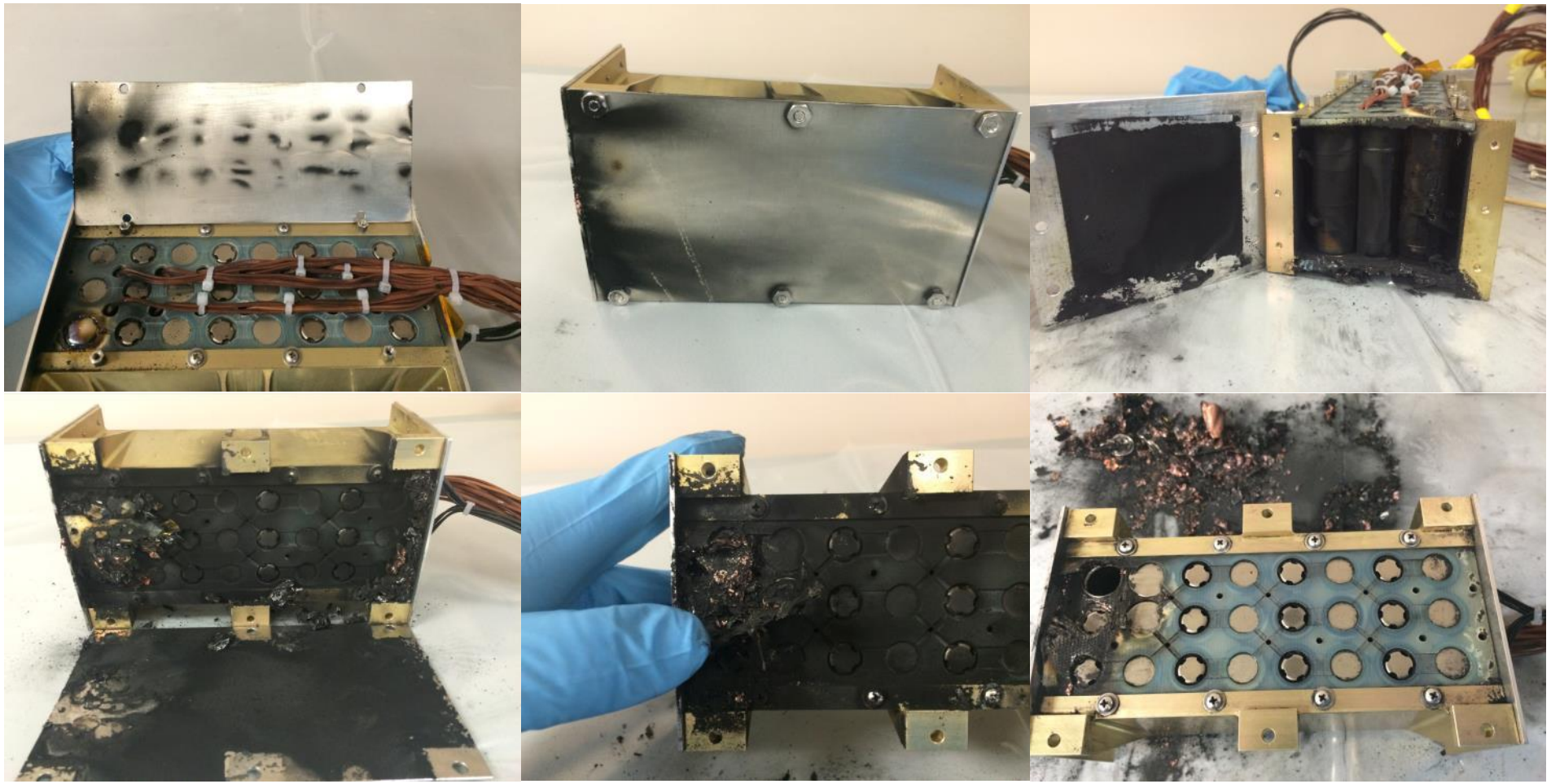
# Moli C Battery Post TR Disassembly



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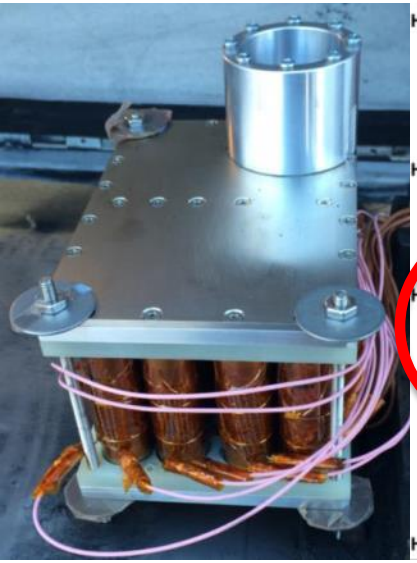
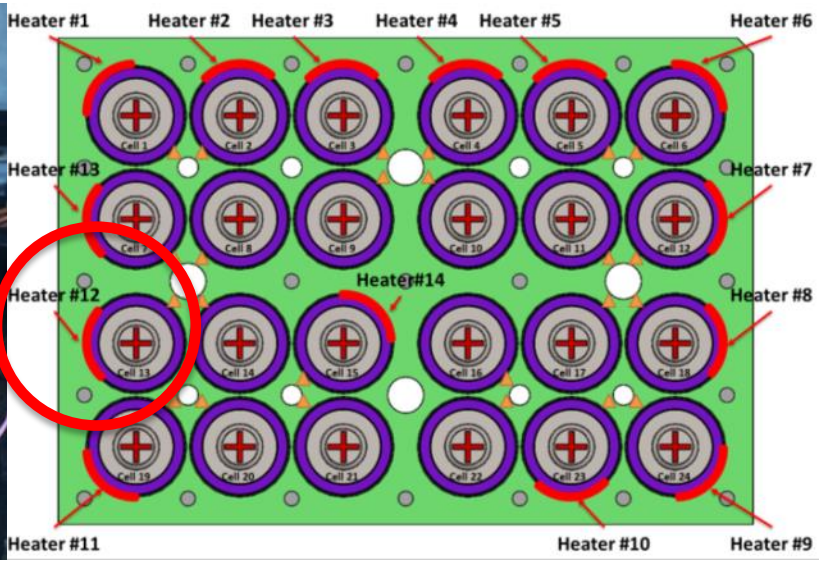
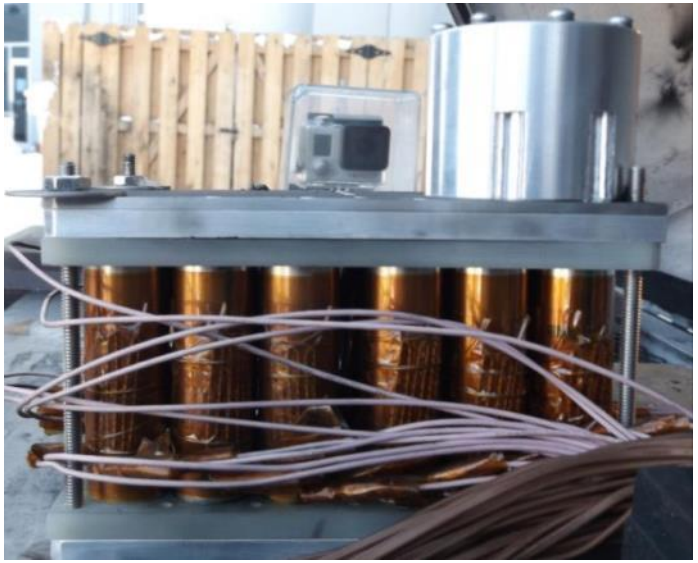
# Moli C Battery Level TR Test 2

- **24 cells built into a cell block**
- **The cells were organized  in four individual 6p1s virtual cells**
  - The cells within a virtual cell were connected electrically, but the virtual cells were not connected to each other
- **Battery had thermocouples attached to all of the cells**
- **Heaters were placed on most of the perimeter cells as shown**
  - Tests were run using heater #3, #6, #10, and #12 (showing results for heater #12)





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# Moli C Battery Level TR Test 2

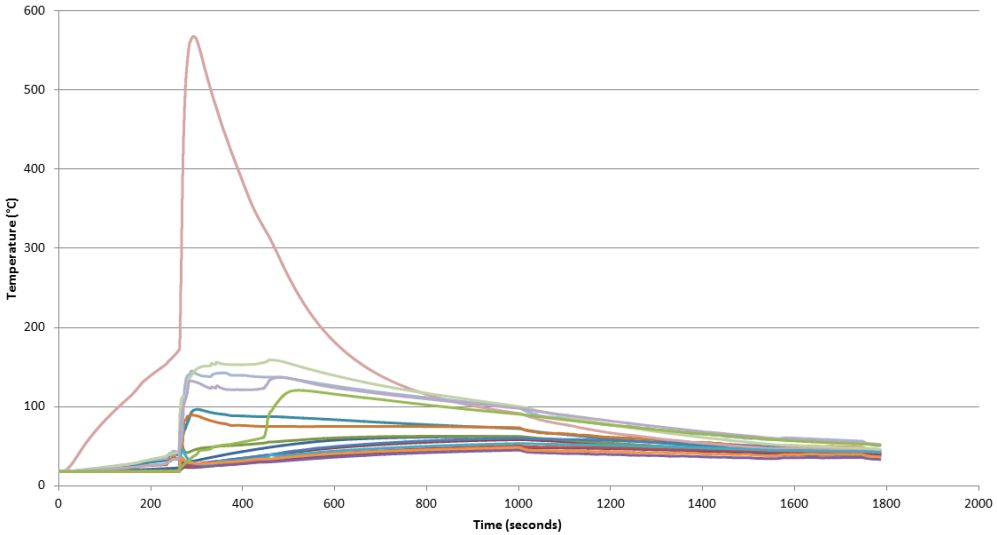
- **Prior to TR, heater was glowing red hot and ignited the kapton on the cell**
- **When the cell went into TR, the burning kapton ignited the flammable gases**
  - The flames surrounding neighboring cells caused cell temperatures to rise
- **Cathode was blown off the cell during**
- **Fragments of the jelly roll were ejected**
- **Jelly roll material was deposited on neighboring cells resulting in the virtual cell shorting**
- **No propagation of TR occurred**
  - The temperature data indicates signs that internal cell safety devices functioned properly to prevent propagation
- **Battery maintained structural integrity**

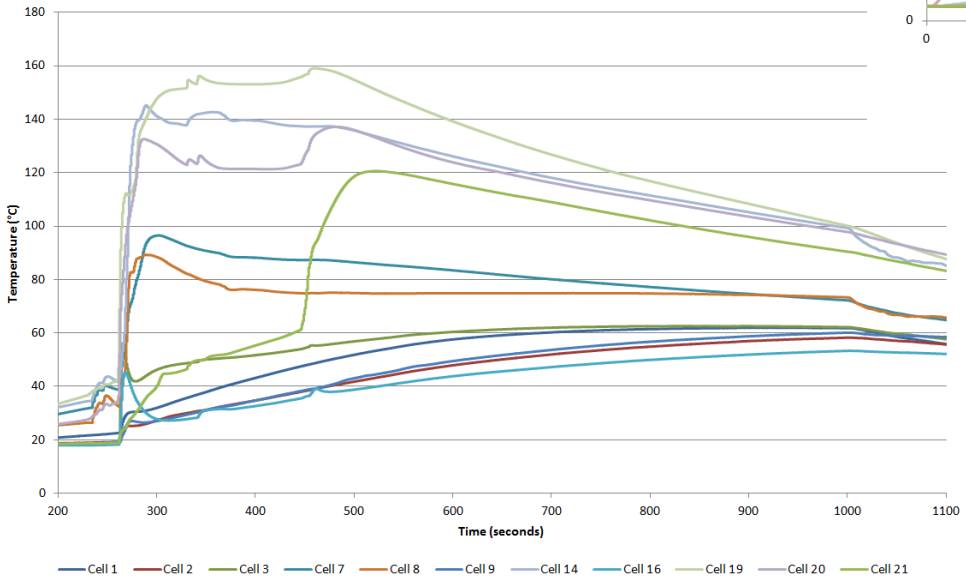
# Moli C Battery Level TR Test 2

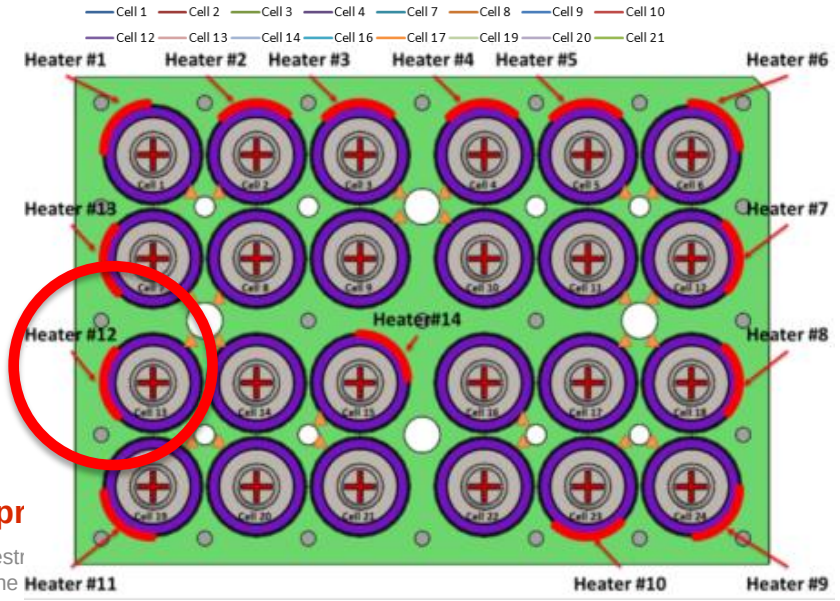


# Moli C Battery Level TR Test 2

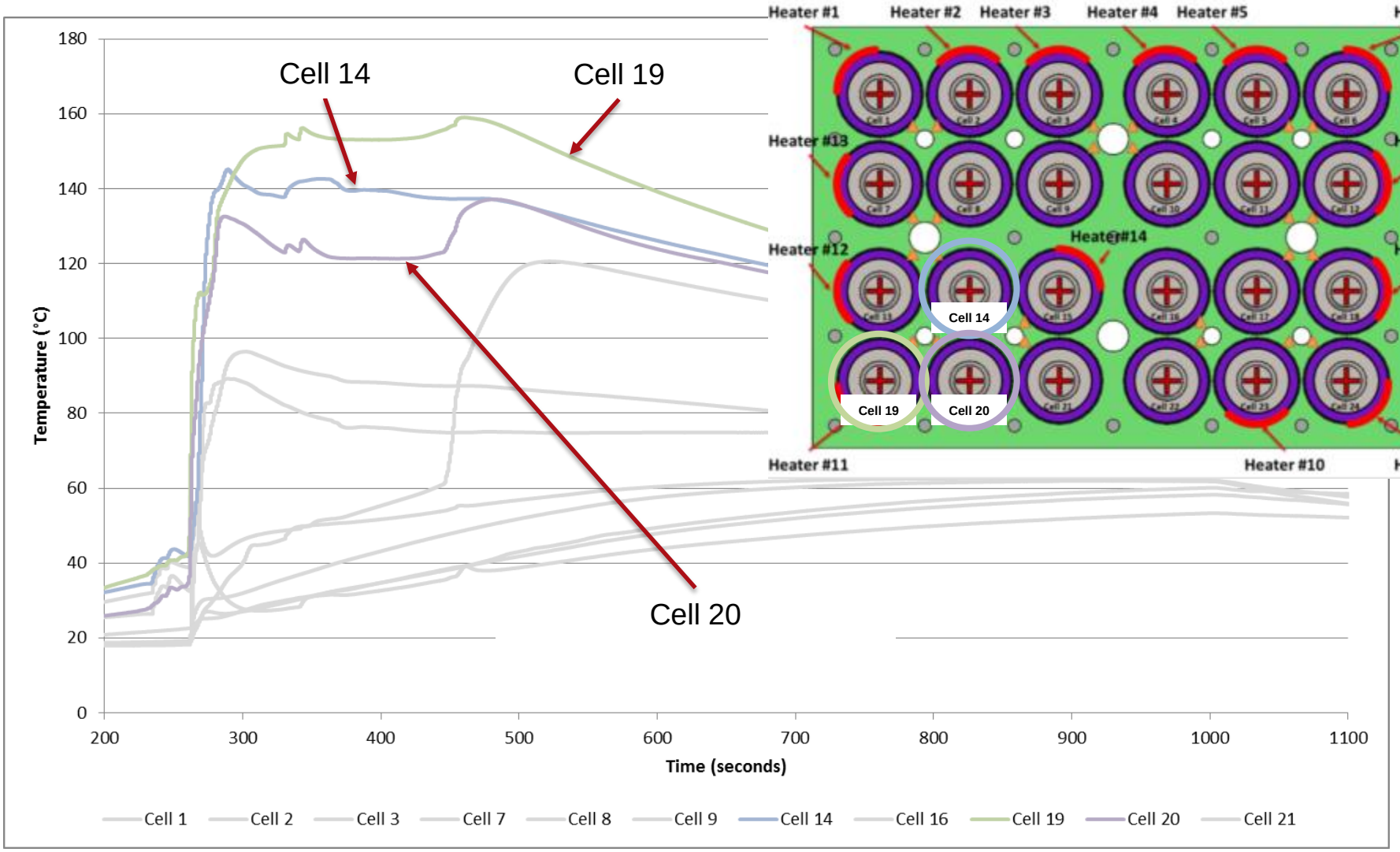
- TR on the trigger cell started at approximately 170°C
- The maximum temperature observed in the neighboring cells was approximately 160°C



# Moli C Battery Level TR Test 2



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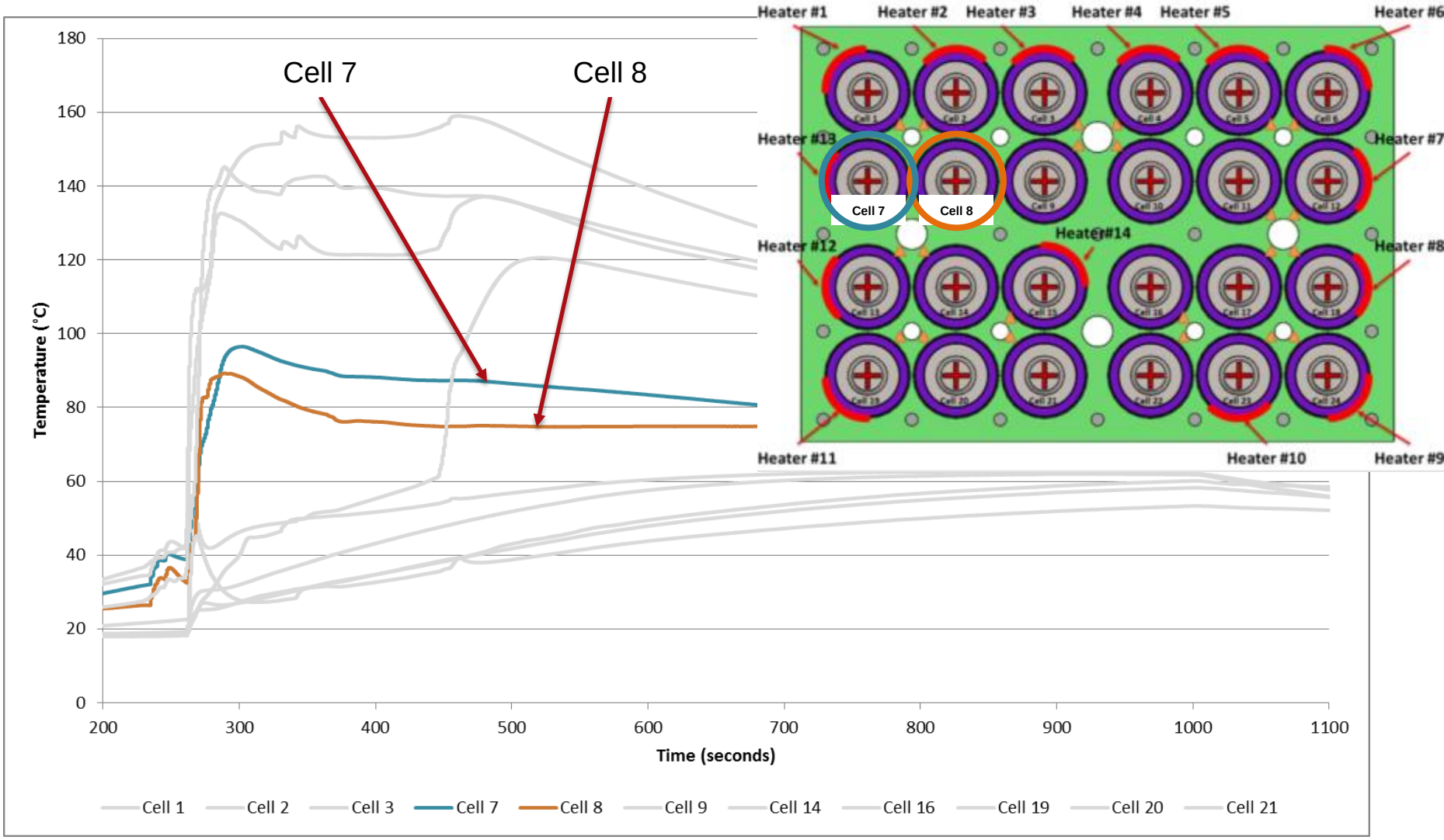
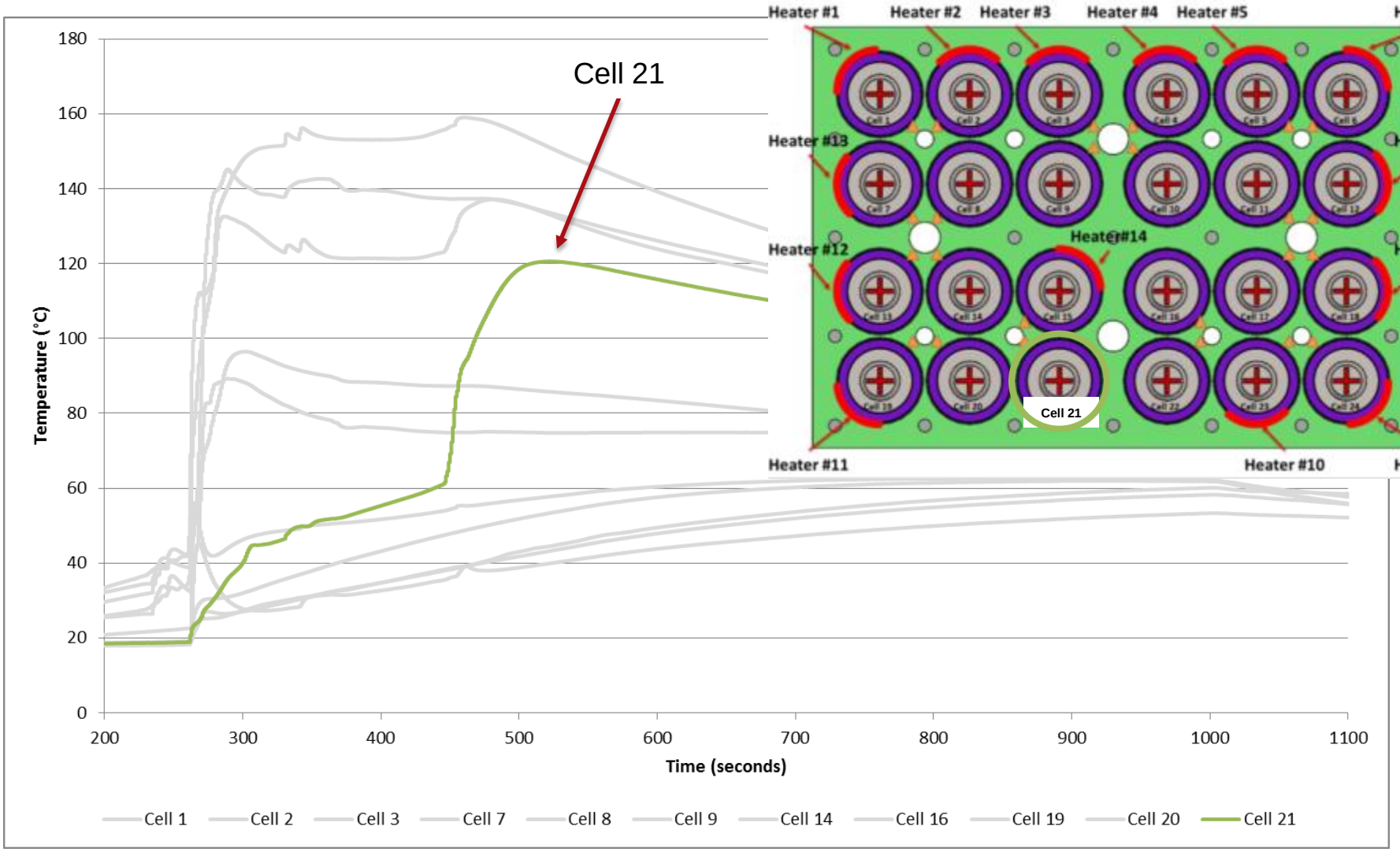
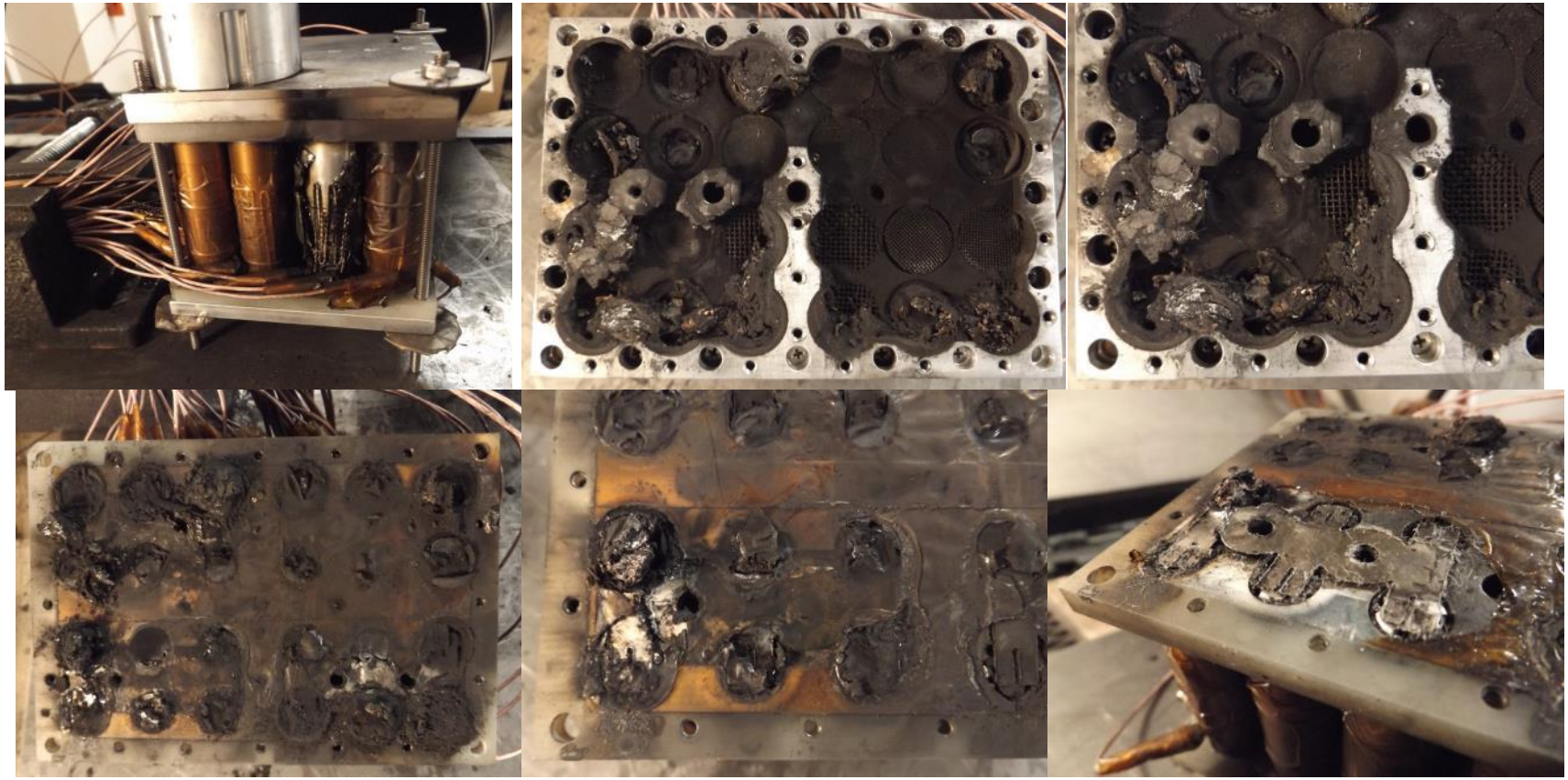


# Moli C Battery Level TR Test 2

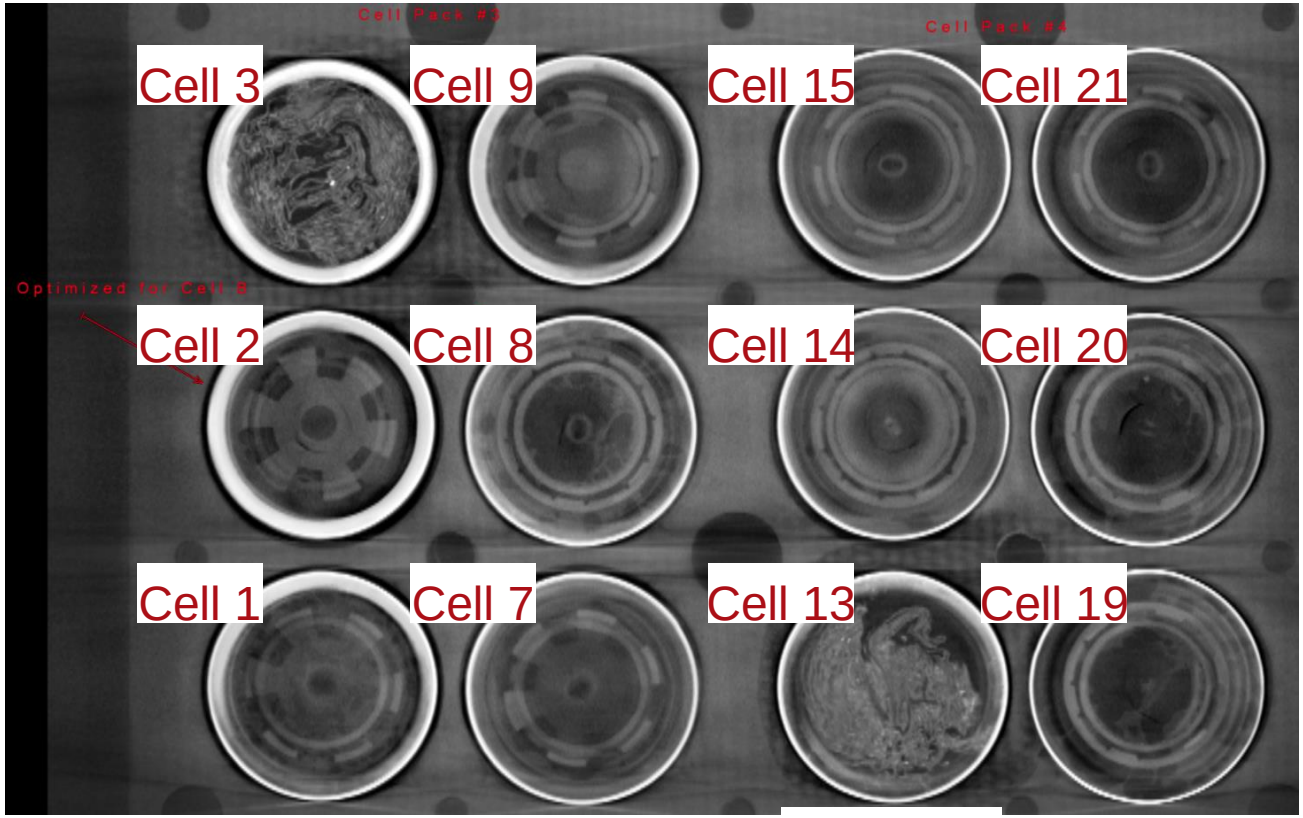


# Moli C Battery Post TR Disassembly



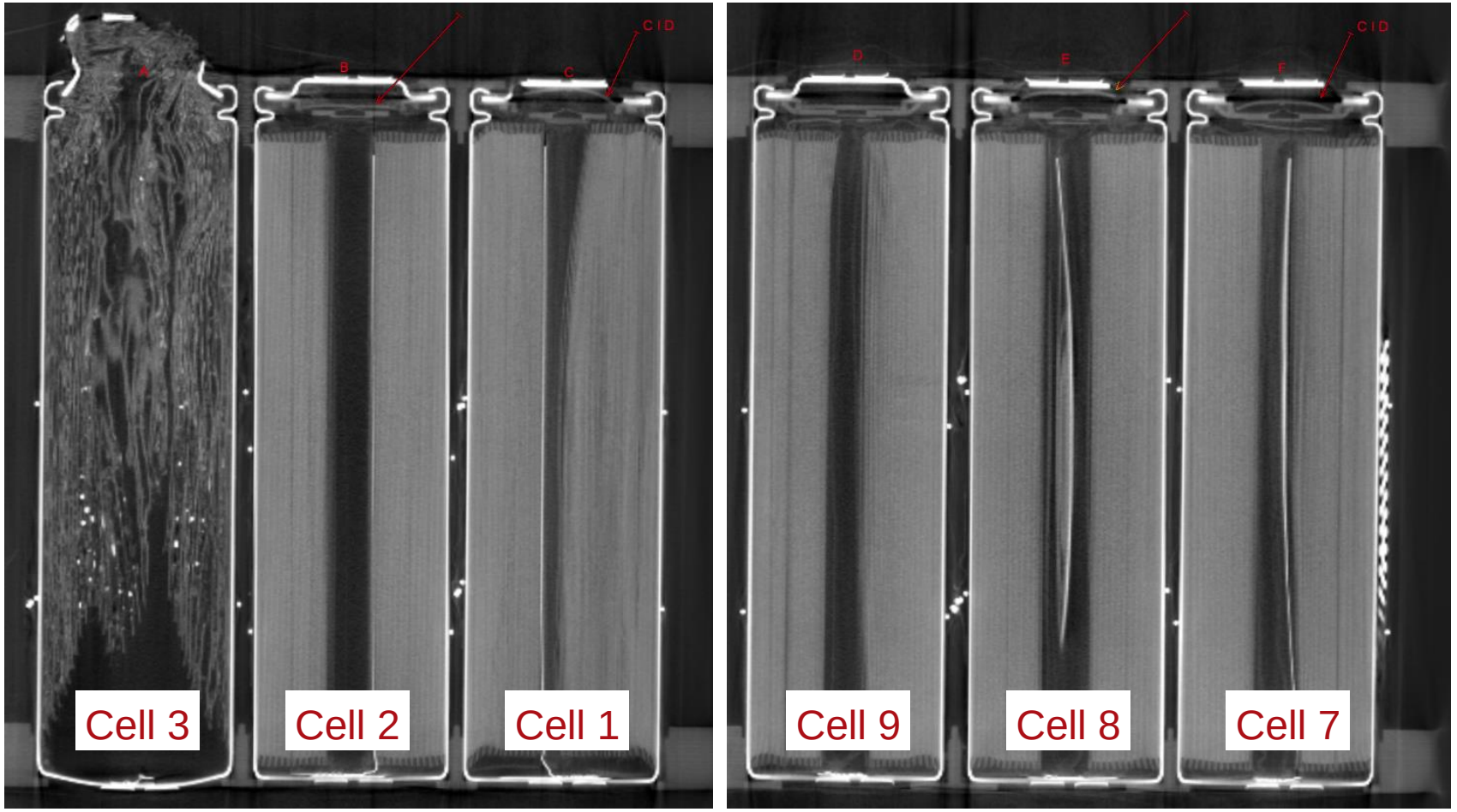
# Moli C Battery CT Scan

- **A CT scan was performed to verify no propagation occurred and to rule out side wall rupture on the trigger cell**



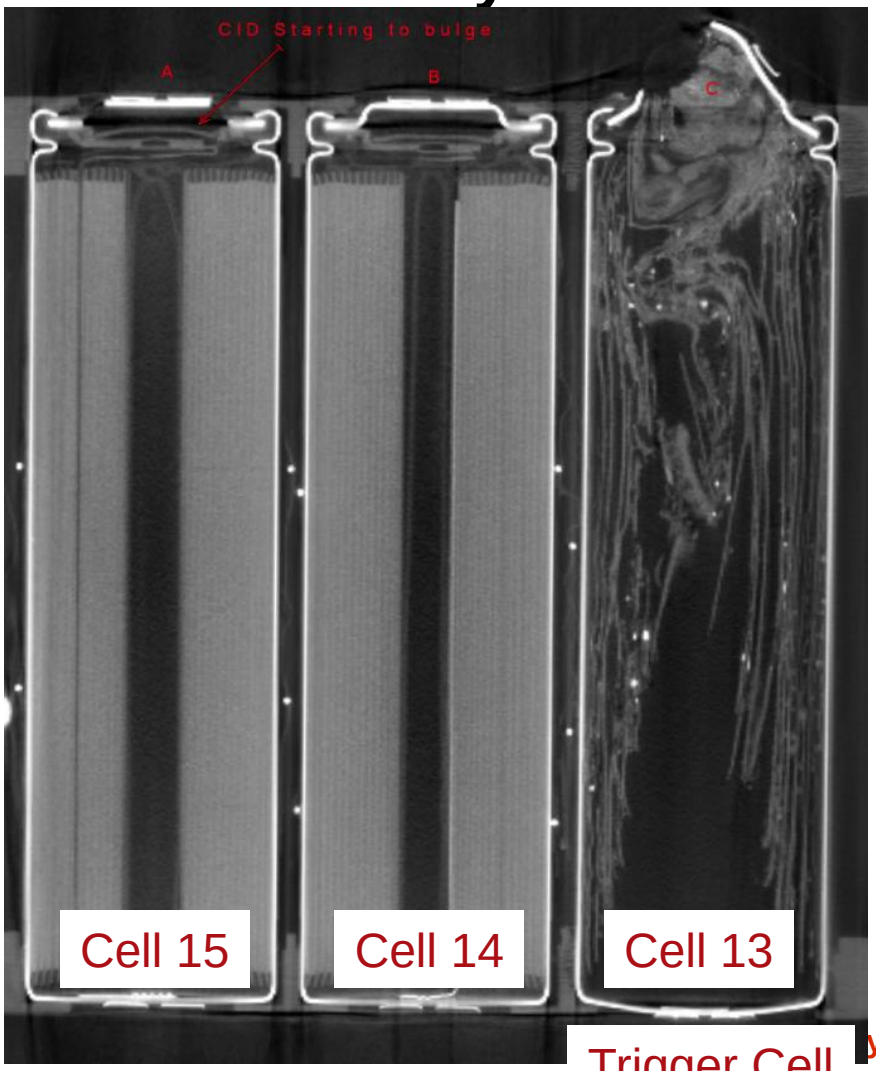

Note: Cell 13 was the trigger cell for this test. Cell 3 was the trigger cell for a test prior to the cell 13 test, it did not go into TR as a result of the cell 13 test

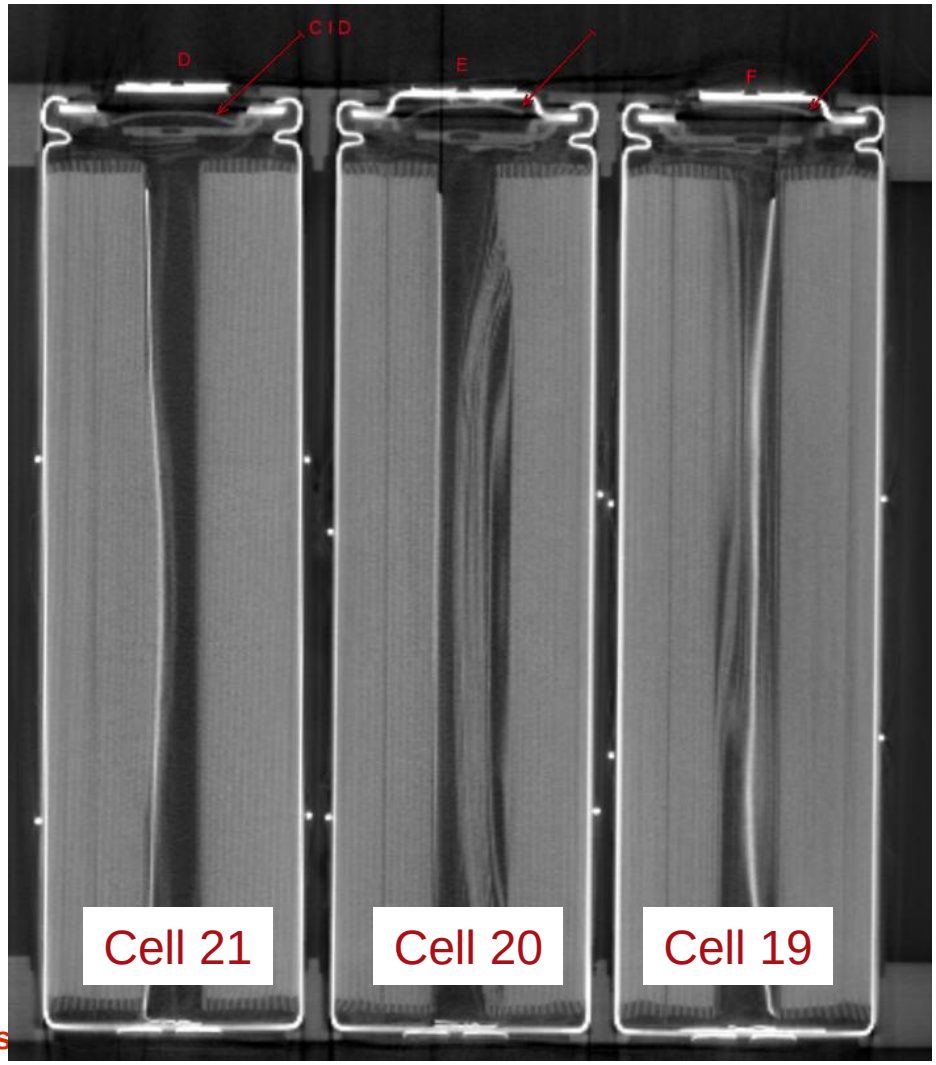
# Moli C Battery CT Scan




Note: Cell 13 was the trigger cell for this test. Cell 3 was the trigger cell for a test prior to the cell 13 test, it did not go into TR as a result of the cell 13 test

# Moli C Battery CT Scan




Trigger Cell

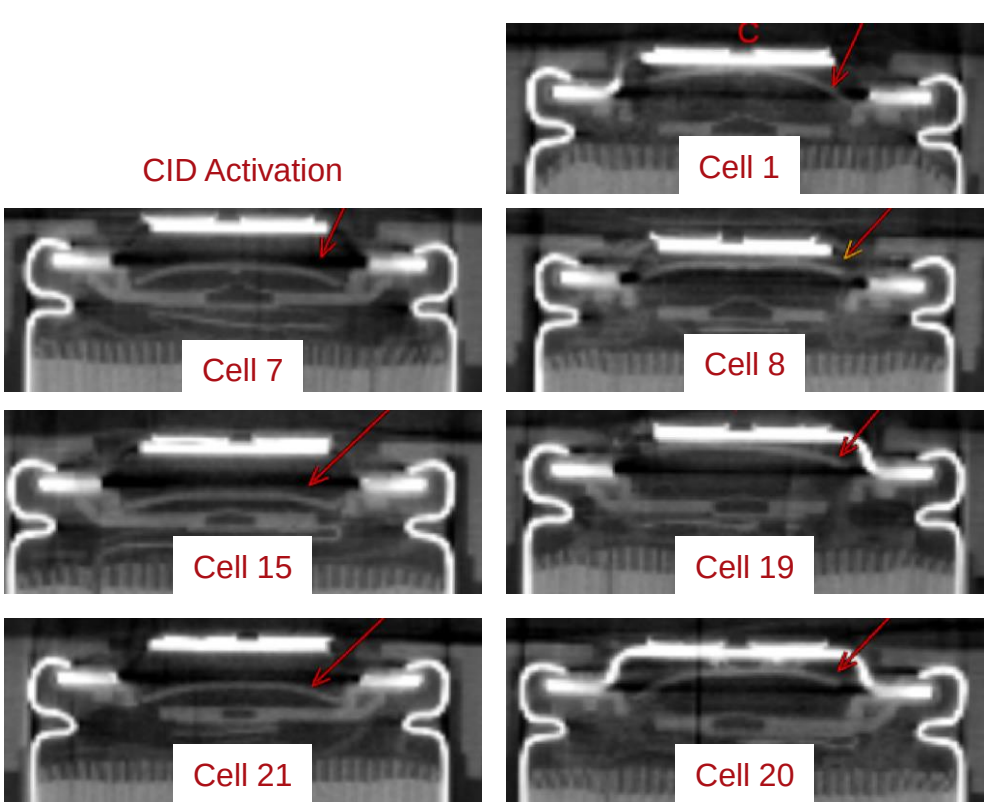
# Moli C Battery CT Scan – Results

**No sidewall ruptures or other gross failures of trigger cells, or neighbor cells**

**GRP damage around trigger cells**

**Neighbor cells normal safety device activation**

- Three cells show CID activation (cell 7, 15, and 21)
  - Pressure disk separated from support disk, but not ruptured
  - Two cells show inconclusive results, CID may have activated but CT scan image not as clear as others (cell 2 and 14)
- Four cells show vent activation (cell 1, 8, 19, and 20)
  - Press disk ruptured at vent groove
- One cell appear undisturbed (cell 9)



## Conclusion

- **2 of 6 HCM battery level tests were discussed here**
  - Results were consistent among all the tests
  - No propagation of TR
  - Battery maintained structural integrity
- **2 of 9 Moli C battery level tests were discussed here**
  - Results were consistent among all the tests
  - No propagation of TR
  - Battery maintained structural integrity

# Questions